SILICE:
A COLOMBIAN SMART MICROGRID PILOT

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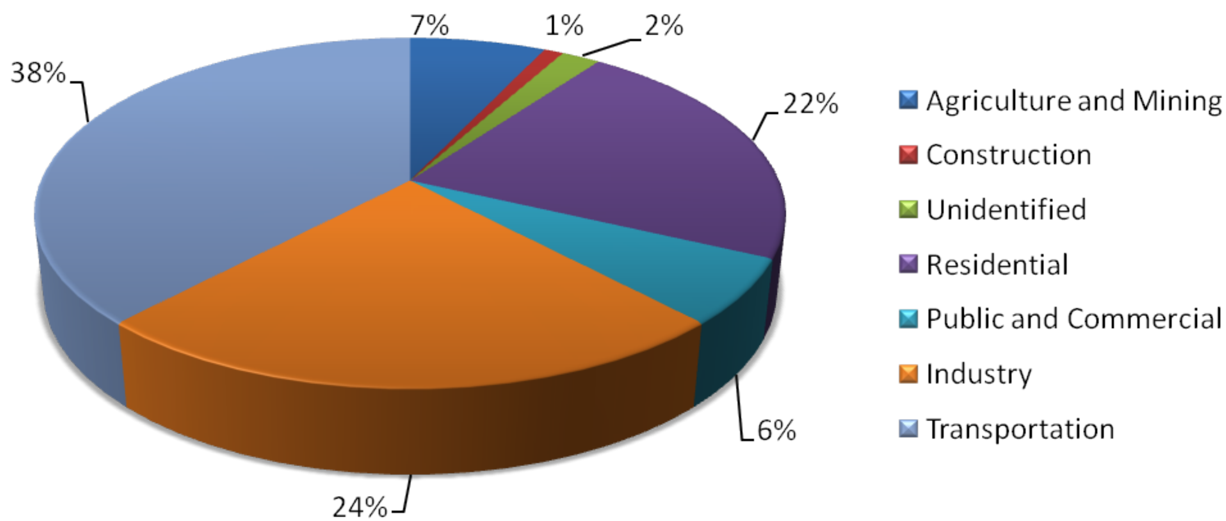
Outline

- Introduction
- SILICE Phase 3
  - DG Applications
  - Demand Response
  - Advanced Metering
  - Integration of Electric Vehicles
- Education
- Conclusions

INTRODUCTION

Context of the Colombian Electric Sector

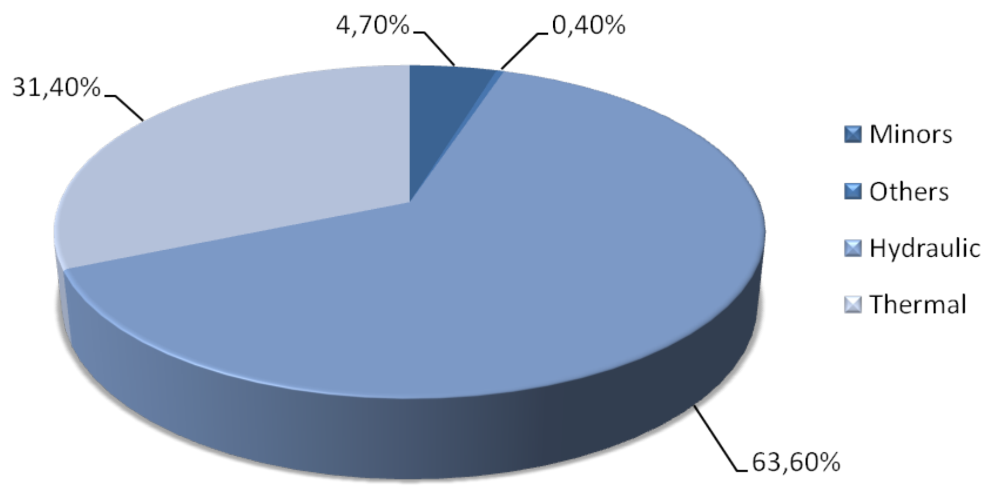
Share of energy demand



- The transportation sector has the greatest amount of energy demand, which means a high use of gasoline and diesel.
- The fossil fuels usage is the main contributor to the Colombian CO2 emissions, while electricity and heat generation are the main sources of world's CO2 emissions.

Context of the Colombian Electric Sector

Share of electricity generation



- In contrast to the commonly share of electricity generation sources, Colombian generation is mainly composed by hydraulic power plants.
- This electricity generation structure implies a low CO2 emissions profile.
- A change in transportation sector energy usage may lead to a lesser carbon intensity. That is, a substitution of combustion vehicles per electric vehicles is required.

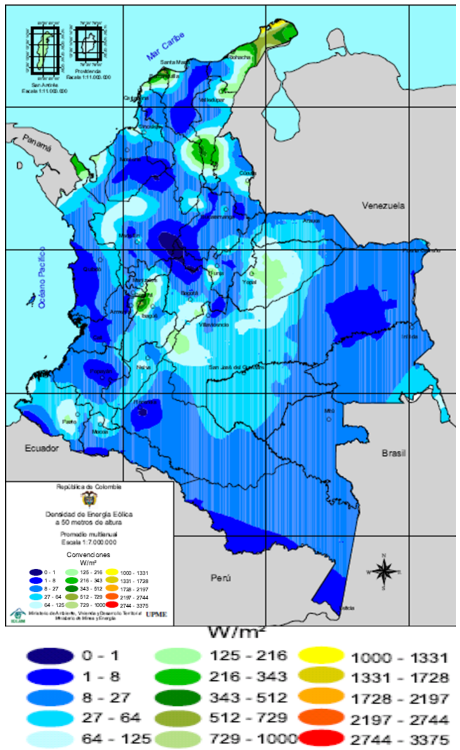
Previous Works

- "Cogeneration in the sugar industry using the ESCO approach"
  - One form of DG was evaluated (i.e., cogeneration). This work was supported by PNUD - ASOCAÑA – Ministerio de Medio Ambiente – UPME
- "Regulation to foster renewable energy and distributed generation in Colombia"
  - Technical and regulatory norms were identified and proposed in the electrical market.

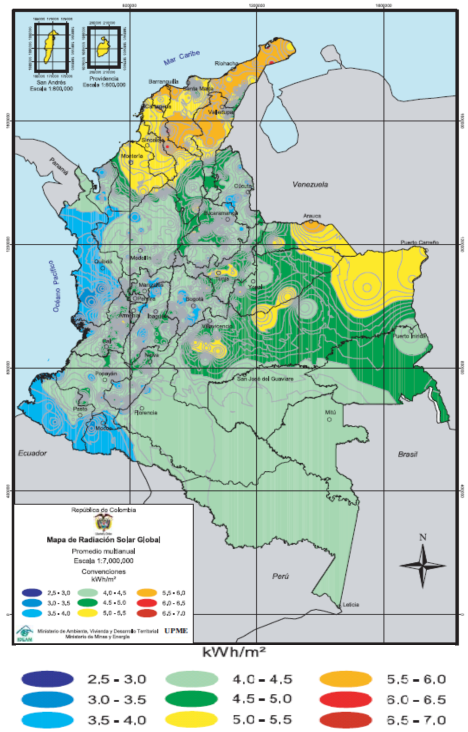
  Universidad Nacional, Universidad de los Andes, Isagen, Colciencias

Generation Potential of Renewable Sources

Wind potential:



Photovoltaic potential:



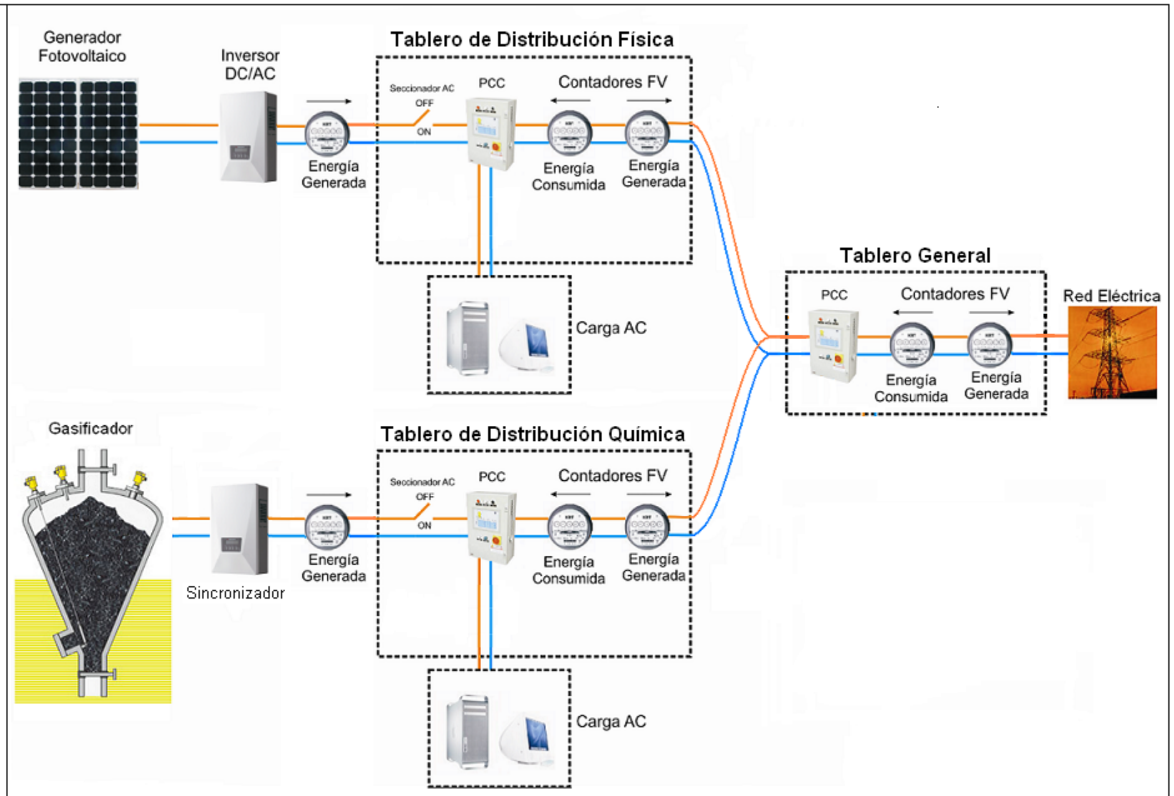
- Wind potential is very low for most of the country. Solely the northern area shows potential above 1 kW per square meter.
- The average photovoltaic potential is about 4 to 5 kW per square meter. Northern area has the highest potential of the country, i.e., 5.5 to 6 kW per square meter.

Main Outcomes Phases 1 and 2

- The main outcomes from the initial two phases, include methodologies for:

- The optimal placement of DG, which has been applied to the installation of minor plants in the Bogotá area.
- The assessment of DG impacts on service quality, from the point of view of the network operator, the users who install DG, and passive users.
- The feasibility evaluation of island operation of DG through the stable and dynamic behavior of a real DS. Here, three types of DG technologies are used (i.e., small hydro, solar, and wind).
- The evaluation of the technical and economic feasibility of using DG to expand energy coverage in rural areas.
- The dispatch of distributed generators in a microgrid and its implications on the power system.
- Demand response programs and measurement on the welfare impacts of higher elasticities in unregulated users.
- Requirements evaluation for an advanced metering network and other communication systems embedded in a smart grid.

Pilot


Generador Fotovoltaico
Inversor DC/AC
Energía Generada
Tablero de Distribución Física
Seccionador AC
OFF
ON
PCC
Contadores FV
Energía Consumida
Energía Generada
Carga AC
Tablero General
PCC
Contadores FV
Energía Consumida
Energía Generada
Red Eléctrica
Gasificador
Sincronizador
Energía Generada
Tablero de Distribución Química
Seccionador AC
OFF
ON
PCC
Contadores FV
Energía Consumida
Energía Generada
Carga AC

SILICE PHASE 3

Project Goals

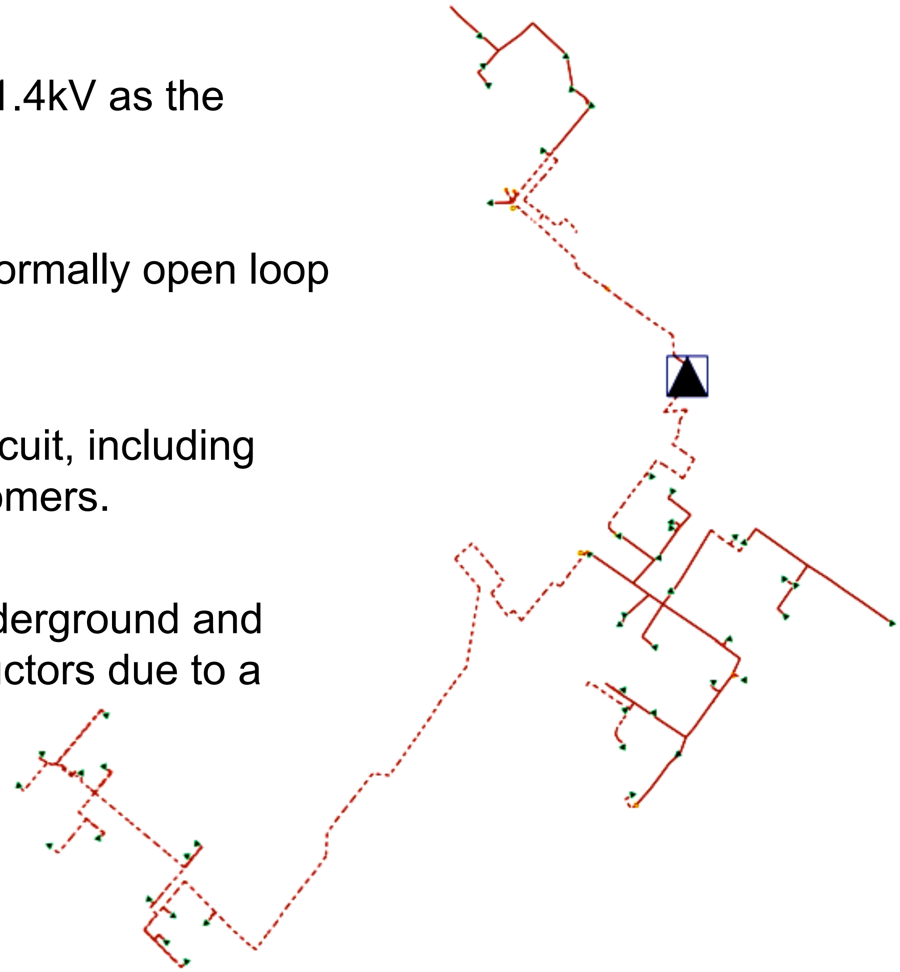
Design the conceptual and basic engineering of a smart microgrid on a distribution circuit, including:

- DG applications and energy storage
- Demand response program
- Energy efficiency
- Advanced metering
- Integration of electric vehicles

Quijano N, Cadena A, Mojica E, Amin M, Annaswamy A, Callaway D, Caramanis M, Chow J, Dotta D, Farid A, Flikkema P, Genc S, Low S, Parisio A, Polis M, Qu Z, Samad T. (2013) **Control-Enabled Smart Grids – Scenarios for 2030 – 2050.** *IEEE Vision For Smart Grid Controls: 2030 And Beyond (ISBN 978-0-7381-8459-3)* pp: 53-84.

Distribution Circuit – Technical Features

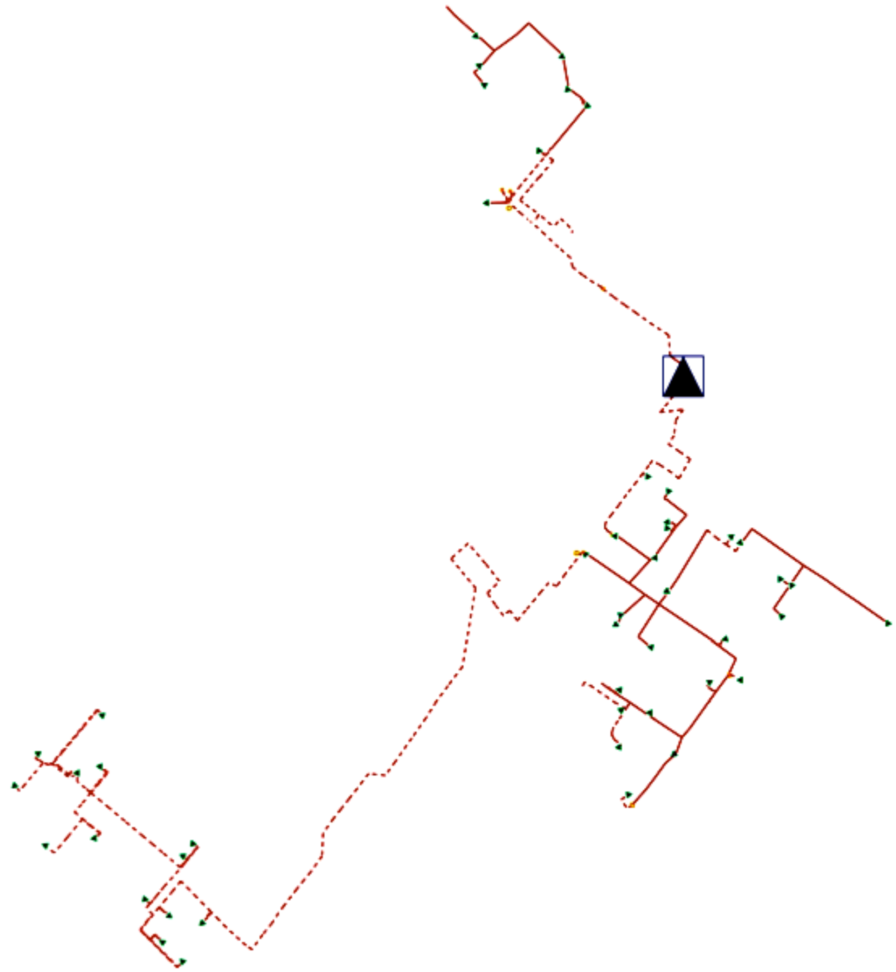
- 8 primary distribution circuits operating at 11.4kV as the nominal voltage.
- Expanded radial system operation, with a normally open loop system.
- 10 MVA average load connected in each circuit, including residential, commercial, and industrial customers.
- The main distribution feeders have both underground and overhead lines, and different types of conductors due to a disordered system expansion.
- Multiple switching devices installed along the feeder.



Distribution Circuit – Technical Features

New elements

- Reclosers – overhead lines
- Switchgears – underground lines
- RTUs
- Advanced metering
- Electric vehicles along with their charge stations
- Distributed generation composed by renewable sources.



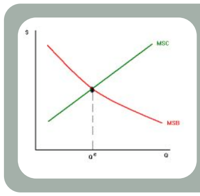
Distribution Automation

- Optimal planning of recloser-based protection systems

Efficient placement of normally open reclosers (NORs)

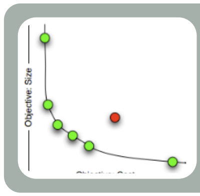
- Active power losses minimization.
- ENS minimization.
- Genetic Algorithm.

Efficient placement of normally closed reclosers (NCRs)



Economic efficiency optimization

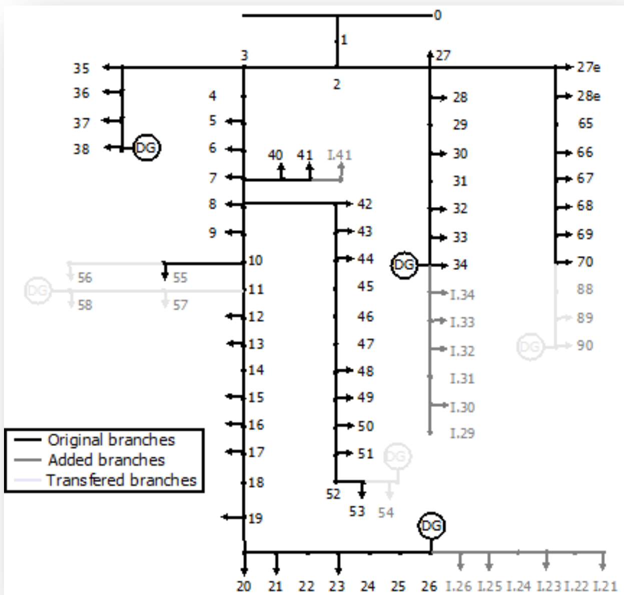
- ENS minimization
- Genetic Algorithm and Differential Evolution



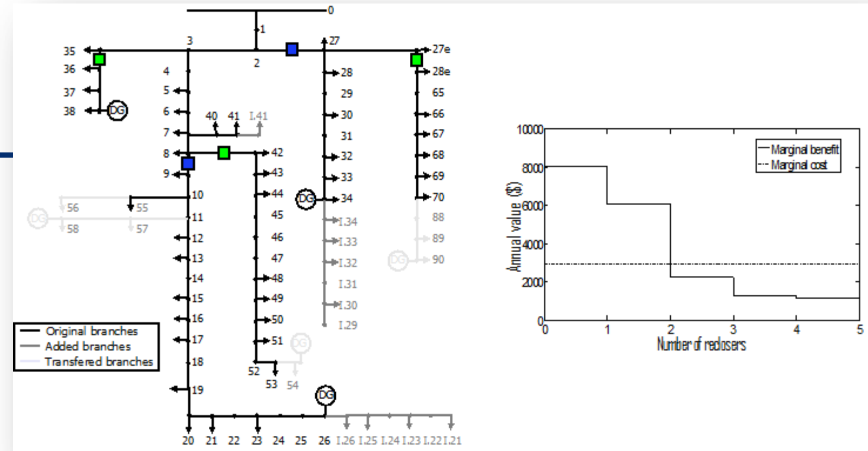
Multiobjective optimization

- SAIFI, SAIDI, and costs minimization
- Multiobjective metaheuristics: NSGS-II and NSDE

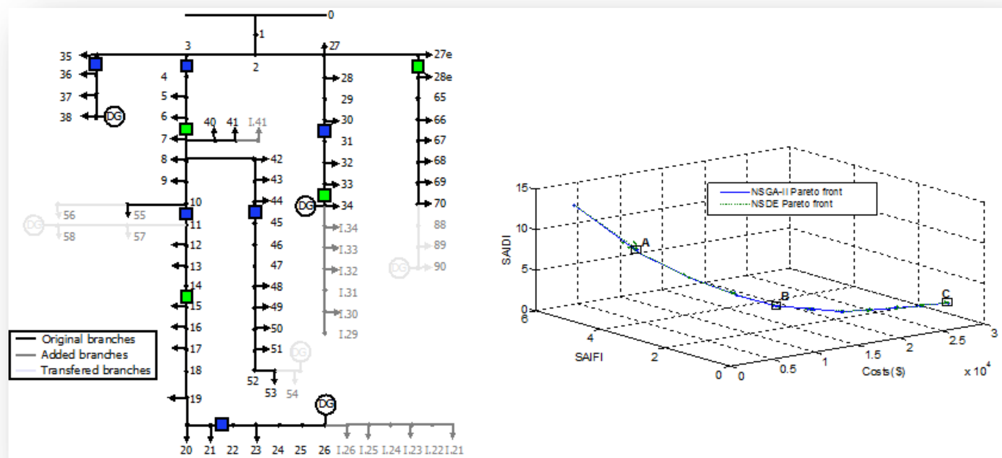
Distribution Automation



NORs placement.



Economic efficiency NCRs placement.



Multiobjective NCRs placement.

Publications

- Optimal planning of recloser-based protection systems applying the economic theory of the firm and evolutionary algorithms, to appear in Proceedings of the 2013 European ISGT-EU.
- Pareto-based multi-stage and multi-objective planning of DG enhanced distribution system , to appear in Proceedings of the 2013 International Conference on Computer and Electrical Engineering.
- Dynamic multi-objective planning for distribution systems with distributed generation , to appear in Proceedings of the 2013 European ISGT-EU.
- Multiobjective planning of recloser-based protection systems on DG enhanced feeders. Submitted paper. IEEE PES Transmission & Distribution Conference & Exposition, T&D 2014.

Electric Mobility

Electric mobility incentives in Colombia

Codensa
- 15 E-vehicles MITSUISHI iMIEV
- 26 E-motorbikes for internal operation
- 48 E-Bike to Work program

Bogotá
- 50 E-taxicab pilot program

The implementation of public transport with EVs mainly involves three challenges:

- Routing to meet transport demand.
- Coordinate energy recharge to ensure reliable operation, avoiding increases in the curve of peak demand .
- Battery care.

Fig. E-vehicles MITSUISHI iMIEV *

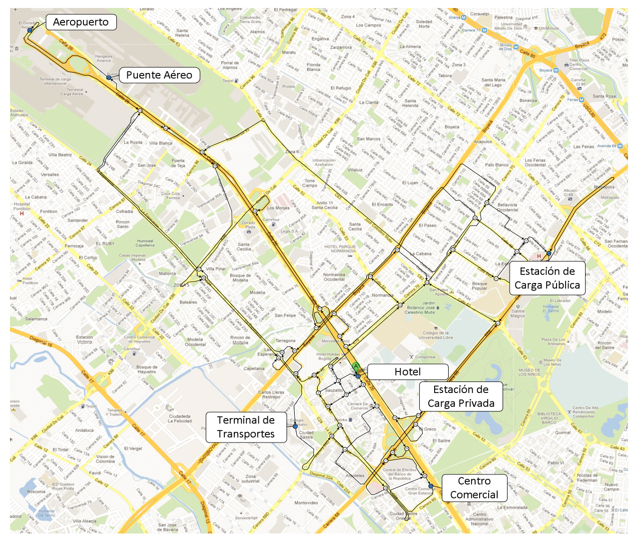
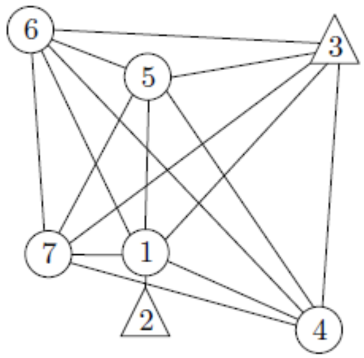


Fig. Operations area of EVs.

* Picture taken from Memoria Annual 2011. Codensa.

Electric Mobility

A centralized controller based on a program that minimizes the operation cost of all Evs is proposed, in which the objective function considers the recharging cost and the battery degradation cost because of routes assignment and recharging actions.



	1	2	3	4	5	6	7
1	0	0	0.23	0.09	0.34	0.45	0.17
2	0	0	0.23	0.09	0.34	0.45	0.17
3	0.28	0.28	0	0.26	0.43	0.54	0.38
4	0.17	0.17	0.30	0	0.47	0.59	0.28
5	0.39	0.39	0.58	0.48	0	0.11	0.41
6	0.38	0.38	0.56	0.46	0.15	0	0.40
7	0.15	0.15	0.35	0.22	0.47	0.58	0

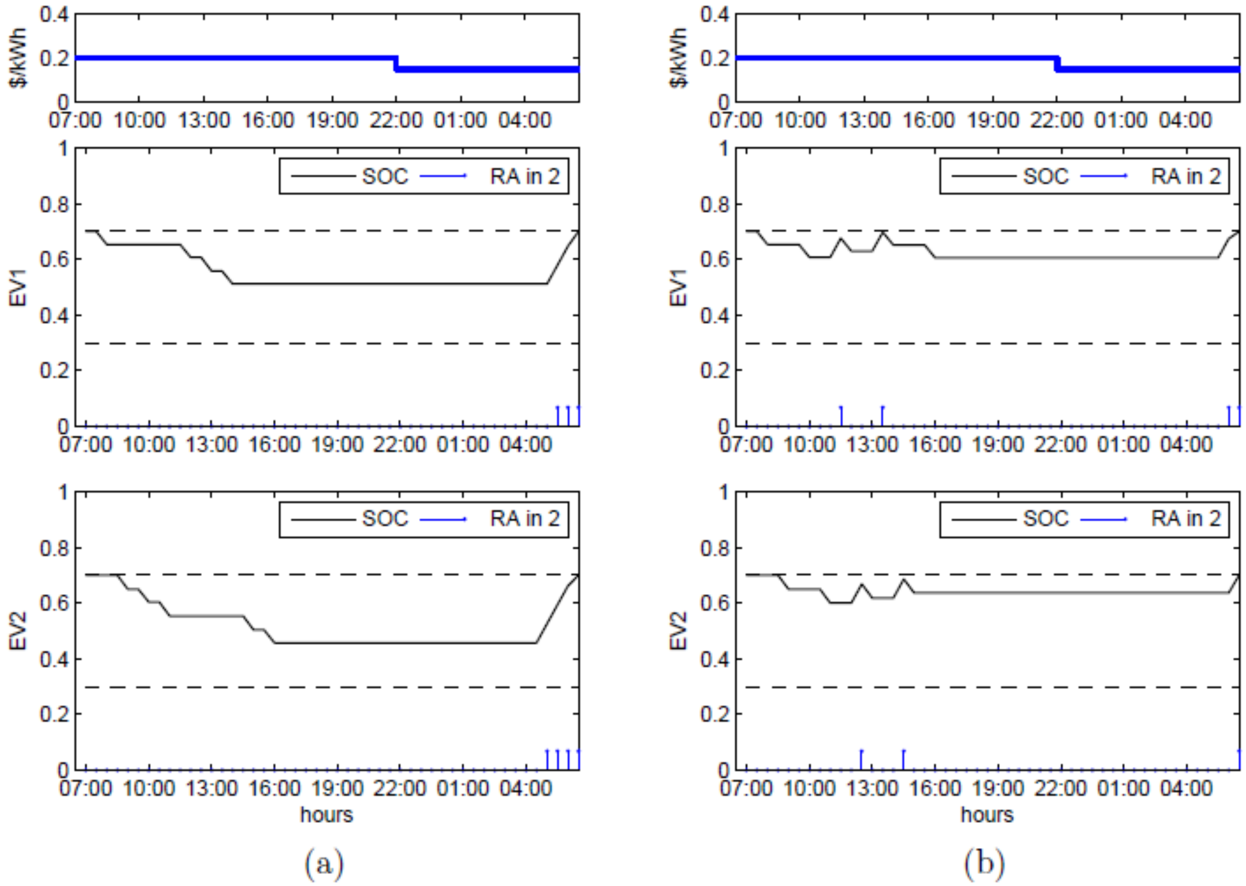
Simplified road graph and consumption energy matrix.

Routes	1	2	3	4	5
Paths	$1,5,6,7,1$	$1,5,6,4,1$	$1,5,6,7,1$	$1,5,6,4,1$	$1,5,6,7,1$
$e^s[kWh]$	1.01	1.10	1.01	1.10	1.01
$[t^s,\ t^e]$	$[7:30,\ 8:21]$	$[8:30,\ 9:26]$	$[9:30,\ 10:21]$	$[10:30,\ 11:26]$	$[11:30,\ 12:21]$

Optimal routing.

Barco J, Quijano N. (2013) **Routing and Scheduling of Recharge for Electric Vehicles.** *Virtual Control Conference on Smart Grid Modeling and Control*

Electric Mobility



Scheduling of recharge for EV1 and EV2 operating in 2 scenarios

Electric Mobility

New constraints to the expansion and operation planning of distribution systems when the optimal placement of charging stations is considered

- Power supply capacity.
- Energy losses and voltage profiles.
- Service quality.
- Station service area with traffic restrictions.

Fig. Charging station *

* Picture taken from Memoria Annual 2011. Codensa.

Distribution Network Reinforcement

- Optimal distribution network reinforcement considering load growth, losses, reliability and distributed generators

New substations

Repowering Substations

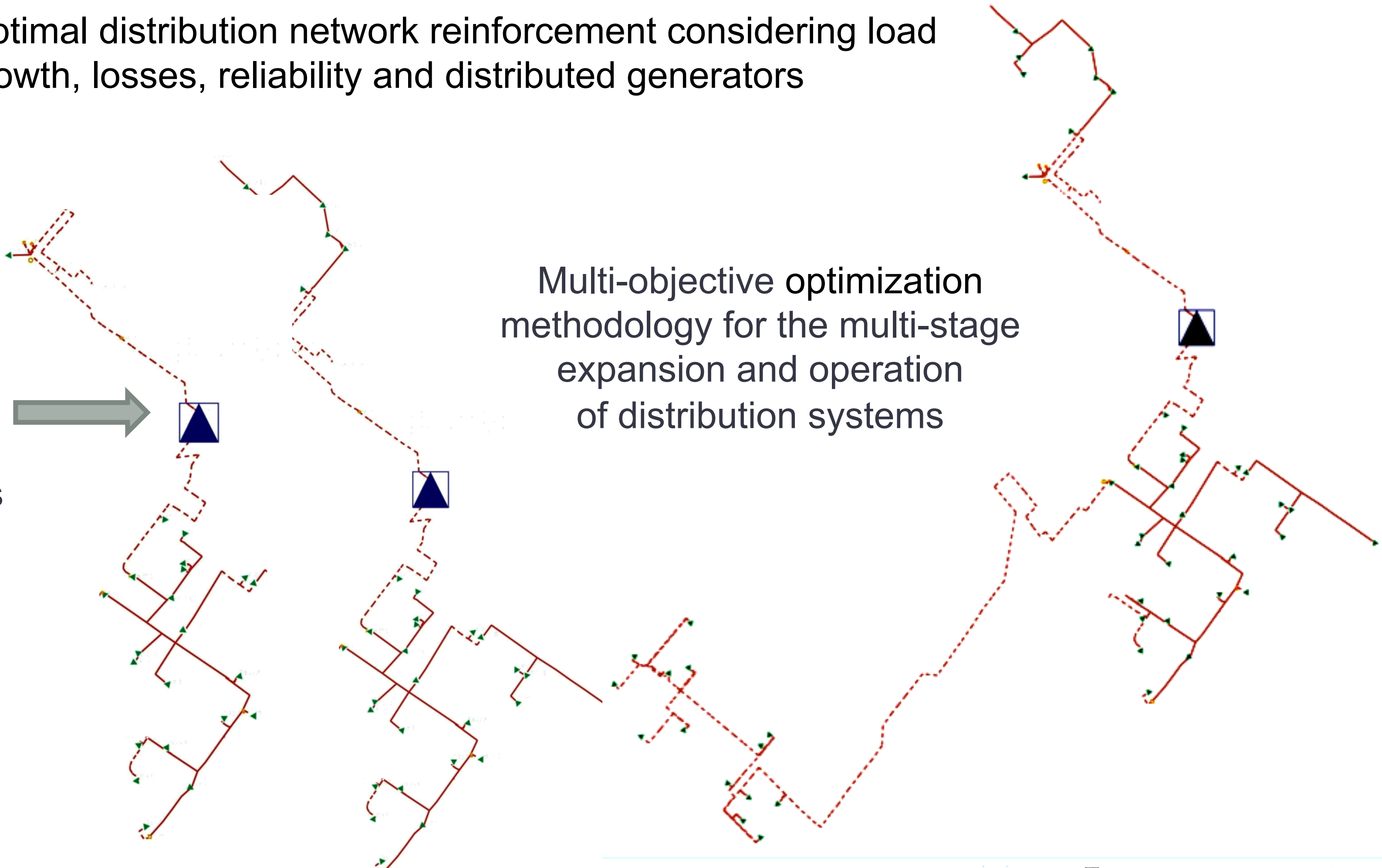
New lines

Rewiring lines

Distributed generation

Capacitor placement

Protection devices



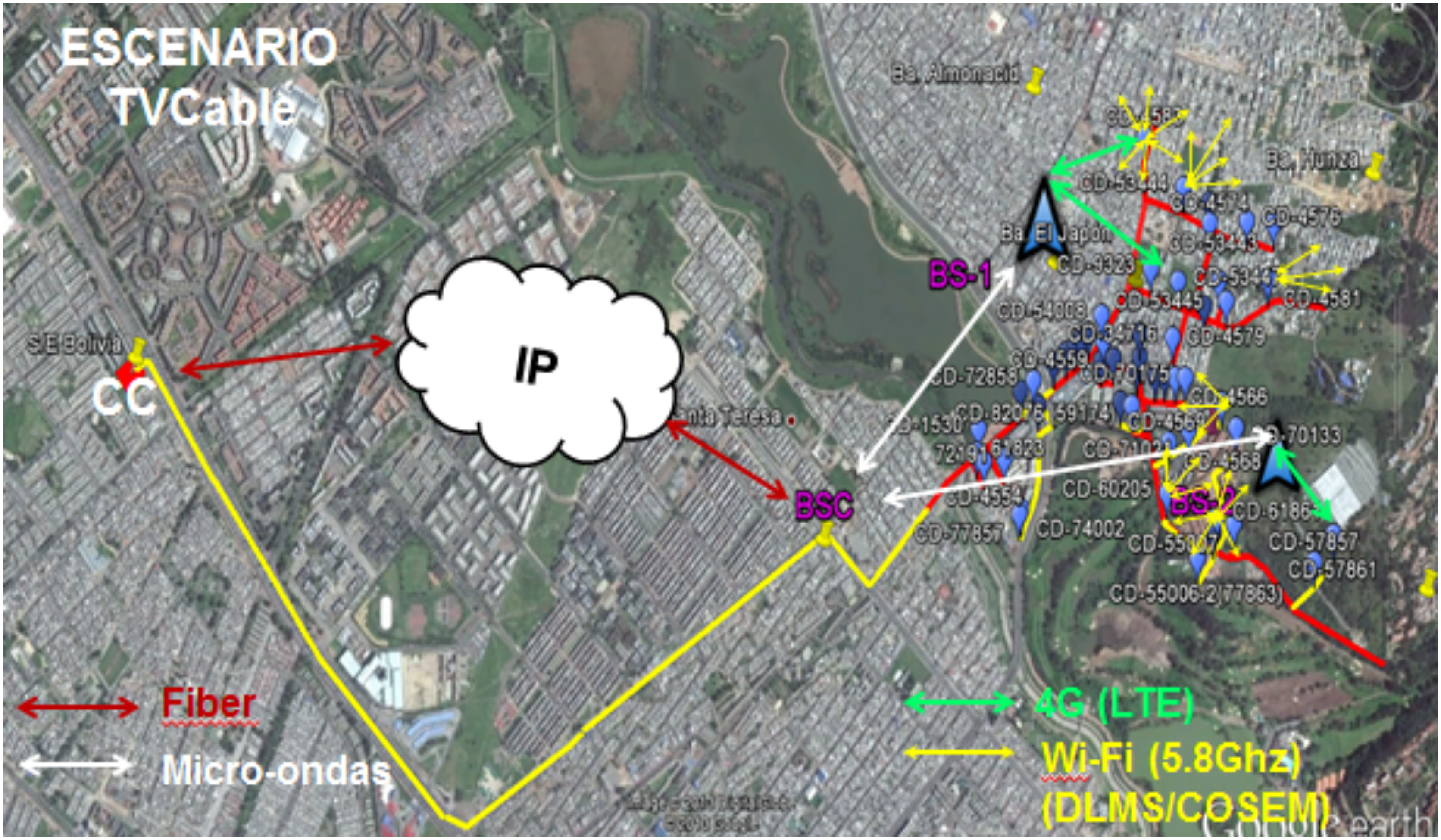
Multi-objective optimization methodology for the multi-stage expansion and operation of distribution systems

Telecommunication Systems and Advanced Metering

End to end architecture

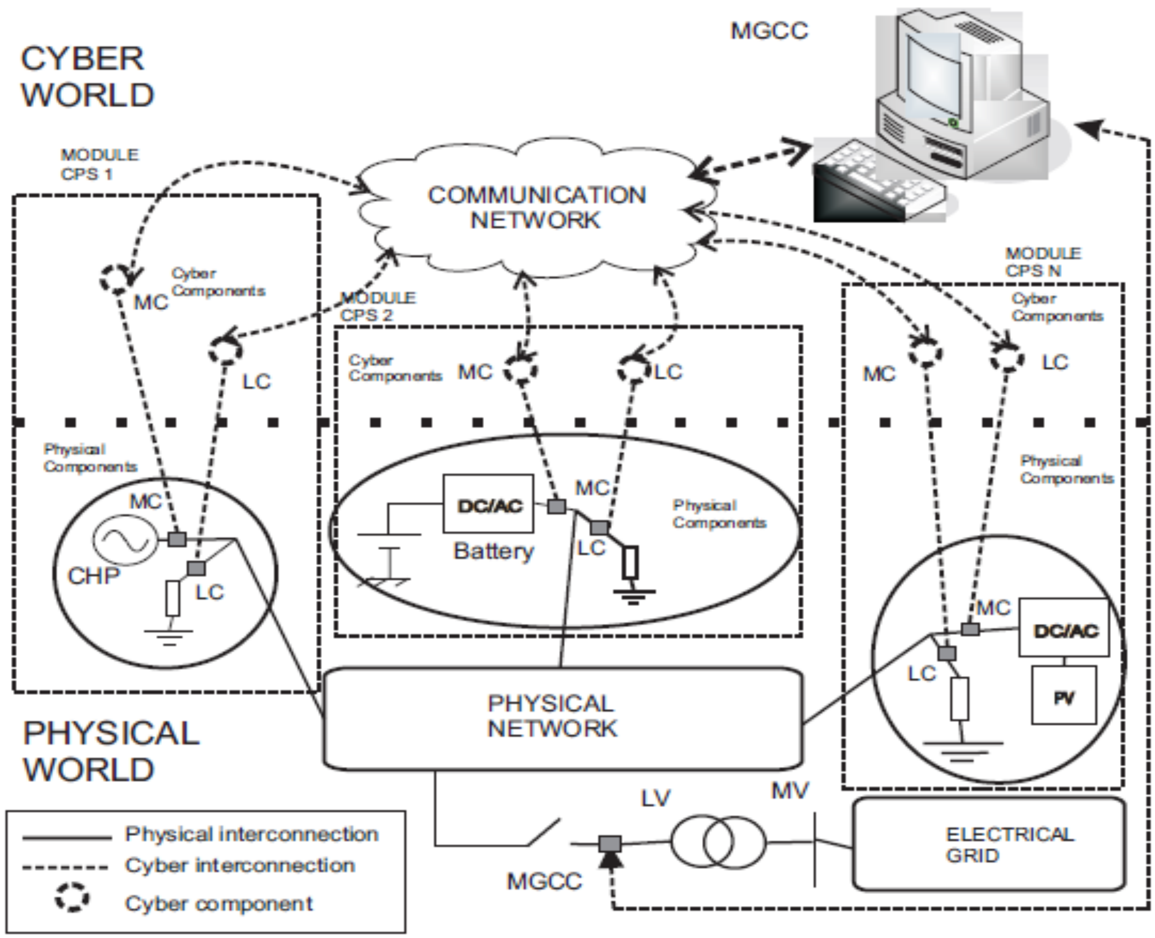
- **SM:** SW and HW implementation (SAGEMCOM, LANDIS + GYR, GE, KAMSTRUP, ZIV)
- **MDMS:** SW implementation (Toshiba, Oracle, Itron, eMeter)
- **AMI Communication network:** Wi-Fi, LTE, Fiber, Ethernet

Telecommunication Systems and Advanced Metering



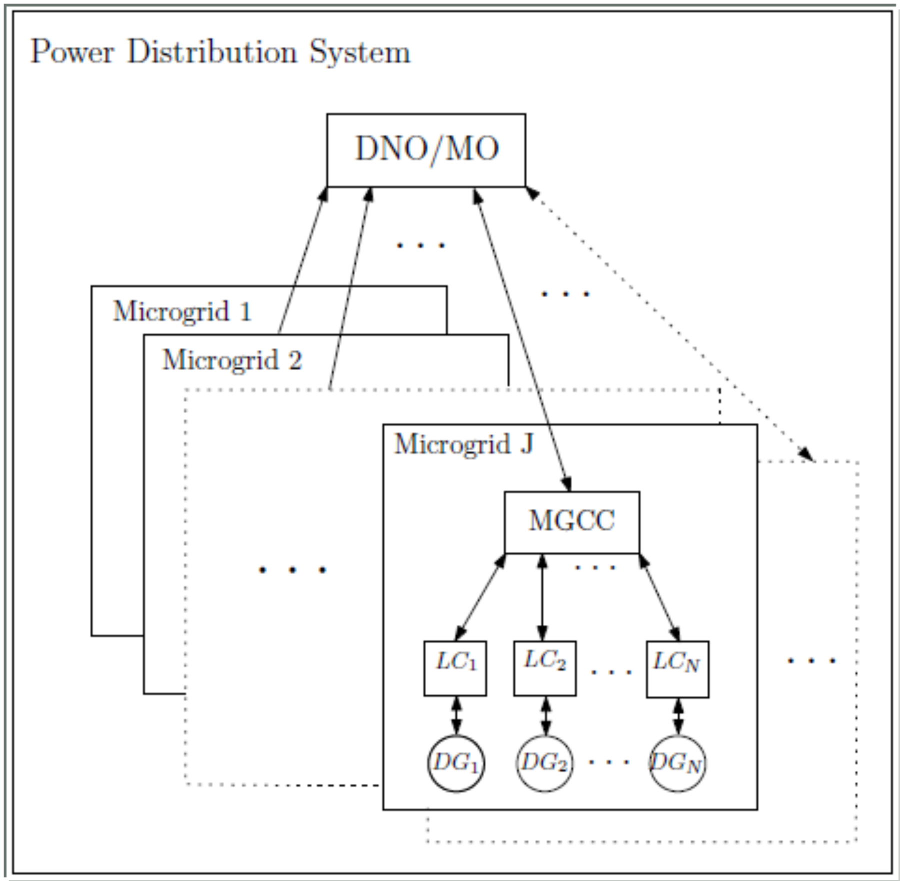
(*) Topology given by CODENSA

Cyber Physical Microgrid Architecture



C. Macana, N. Quijano, and E. Mojica-Nava, “A survey on cyber physical energy systems and their applications on smart grids,” in IEEE PES Conference on Innovative Smart Grid Technologies (ISGT Latin America), 2011

Distributed Generation and Microgrids
Hierarchical and Distributed Strategy

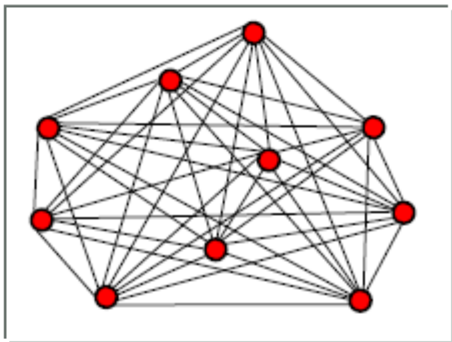


- DGs grouped in microgirds.
- Distributed Network Operator and / or market Operator (DNO/MO).
- Central controller for each Microgris (MGCC).
- Local controller for each DG (LC).
- A dispatch strategy for each DG.

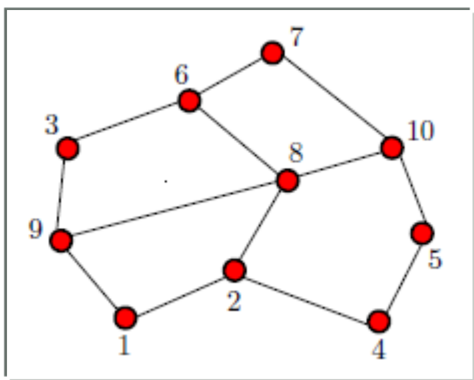
Application of Replicator Dynamics

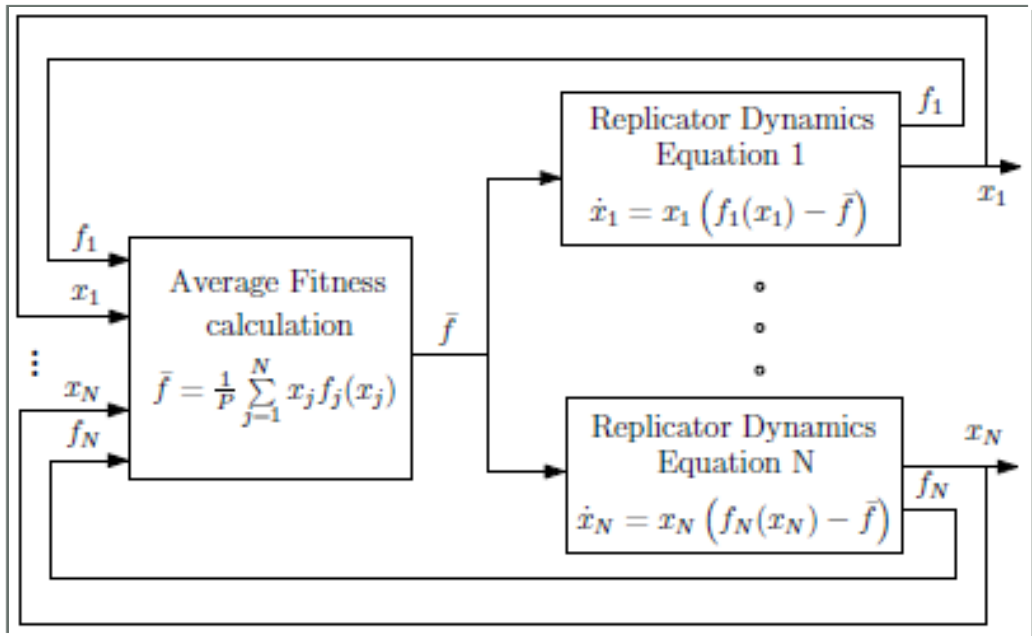
Centralized, Distributed - Implementation

System with Global Information



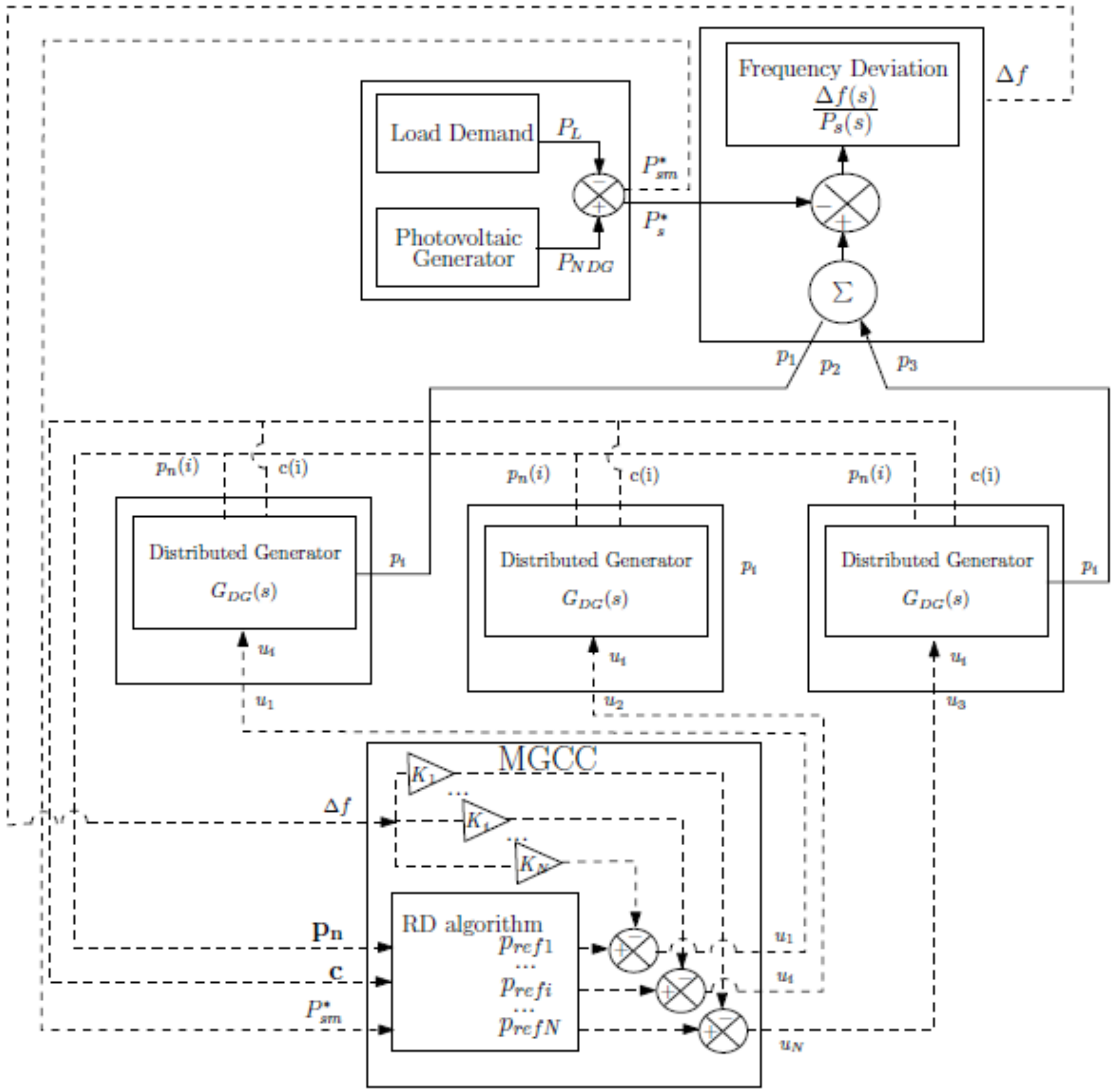
System with Local Information





Pantoja A, Quijano N. (2011)
[A Population Dynamics Approach for the Dispatch of Distributed Generators.]
IEEE Transactions on Industrial Electronics (ISSN 0278-0046) 58(10), pp. 4559-4567

Load Frequency Control in Microgrids Replicator Dynamics Control Strategy



Mojica E, Quijano N, Pavas A. **Dynamic Population Games for Hierarchical Microgrid Management.** *In Proceedings of the 2013 IEEE ISGT Europe*

Macana C, Mojica E, Quijano N. (2013) **Time-Delay Effect on Load Frequency Control for Microgrids.** *Proceedings of the 2013 IEEE International Conference on Networking, Sensing And Control*

Demand Response and Frequency Syncronization

- We have designed economical and social incentives, which are able to modify the habits of the consumers. For that, we have used classical economical models and population dynamical concepts.

- We have designed a networked distributed control scheme, in order to guarantee the frequency syncronization between microgrids.

Giraldo J, Mojica E, Quijano N. **Synchronization of Dynamical Networks Under Sampling.** *Proceedings of the 2013 European Control Conference*

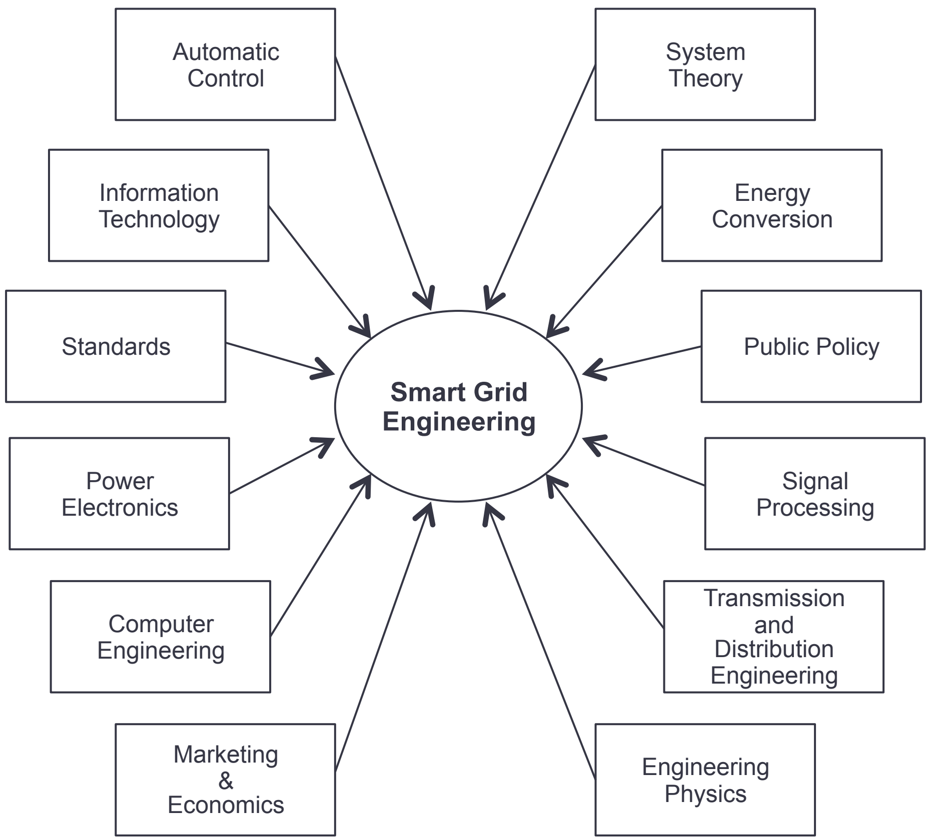
Carlos Barreto, Mojica E, Quijano N. (2013) **Design of Mechanisms for Demand Response Programs,** to appear in Proceedings of the 2013 IEEE CDC

Carlos Barreto, Mojica E, Quijano N. (2013) **A Population Dynamics Model for Opinion Dynamics with Prominent Agents and Incentives, in** *Proceedings of The 2013 American Control Conference*

EDUCATION

IELE 4113: Redes Inteligentes y Generación Distribuida

Challenges



M. Kezunovic, “Teaching the smart grid fundamentals using modeling, simulation, and hands-on laboratory experiments," in IEEE Power and Energy Society General Meeting, 2010, pp. 1-6, IEEE, 2010.

Objectives

- Understand the concepts associated with smart grids an distributed generation. This objective would satisfy criteria 3a) and 3k) from ABET.
- Integrate the different areas of the electrical engineering: Power and Energy, Control Systems, Telecommunications and Economics and Regulation. This objective would satisfy criterion 3d) from ABET.
- Design a Smart Grid with distributed generation for a region in Colombia. This objective would satisfy criteria 3a), 3b), 3c), 3d), 3e), and 3k) from ABET.
- Present the results of the proposed Smart Grid design. This objective would satisfy criterion 3g) from ABET.
- In order to meet these objectives, we gather some feedback from the students by means of different types of evaluations. In this case, the course is evaluated with two midterm exams (50%) and one final project (50%).

Final Project

- The project consists in the design of a microgrid based on the IEEE 13-bus test feeder for a given geographic region.
- It is expected that the students apply the main topics presented along the course (e.g., choose the feasible technologies and place the optimal generation according to one (or more) of the different criteria).
- The students should propose and precise the type of load and the number of users located at each bus of the test feeder. Also, they should propose the technical and economical characteristics of the SCADA and later, perform a short-circuit analysis at every node (before and after installing the distributed generators).
- Based on the results of the optimal placement algorithm, students must perform the dispatch of the distributed generators in the microgrid, considering the technical (e.g. nominal power) and economical characteristics of each generator.
- The students design a telecommunications network satisfying the specific QoS requirements for the different applications inside the Smart Grid (e.g., load control, energetic dispatch, AMR).
- Finally, they should update and complete the economic evaluation of the project, including the environmental issues.

CONCLUSIONS

Conclusions

- We have made several contributions from a theoretical point of view, which we hope can be integrated in new smart grid projects that Codensa has (e.g., Salitre Inteligente).
- The knowledge acquired is presented in a master's level course, in order to show the students how different areas can work together in a real engineer problem.
- Silice was the first project that studied smart grid ideas. Today, there are other initiatives in Colombia (e.g., Colombia Inteligente, and other companies are developing there own microgrids).

Acknowledgements

- This work is supported by Emgesa-Codensa-Endesa (Innovation Division) and Colciencias (Department of Science, Technology, and Innovation) under contract number 387-2012 (Sept 2012 - Sept 2014).
- The research group SILICE has included professors (14), post-docs (2), PhD students (9), masters students (26), and undergraduate students (10), who we would like to thank.
- Finally, we would like to thank Guillermo Jiménez and all the organizers for the invitation.